REPORT OF THE BOARD OF COMMISSIONERS

OF THE

...mento River Drainage District

TO THE

GOVERNOR OF CALIFORNIA.

SACRAMENTO:
STATE OFFICE : : : F. P. THOMPSON, SUPT. STATE PRINTING.
1879.

REPORT OF THE BOARD OF COMMISSIONERS

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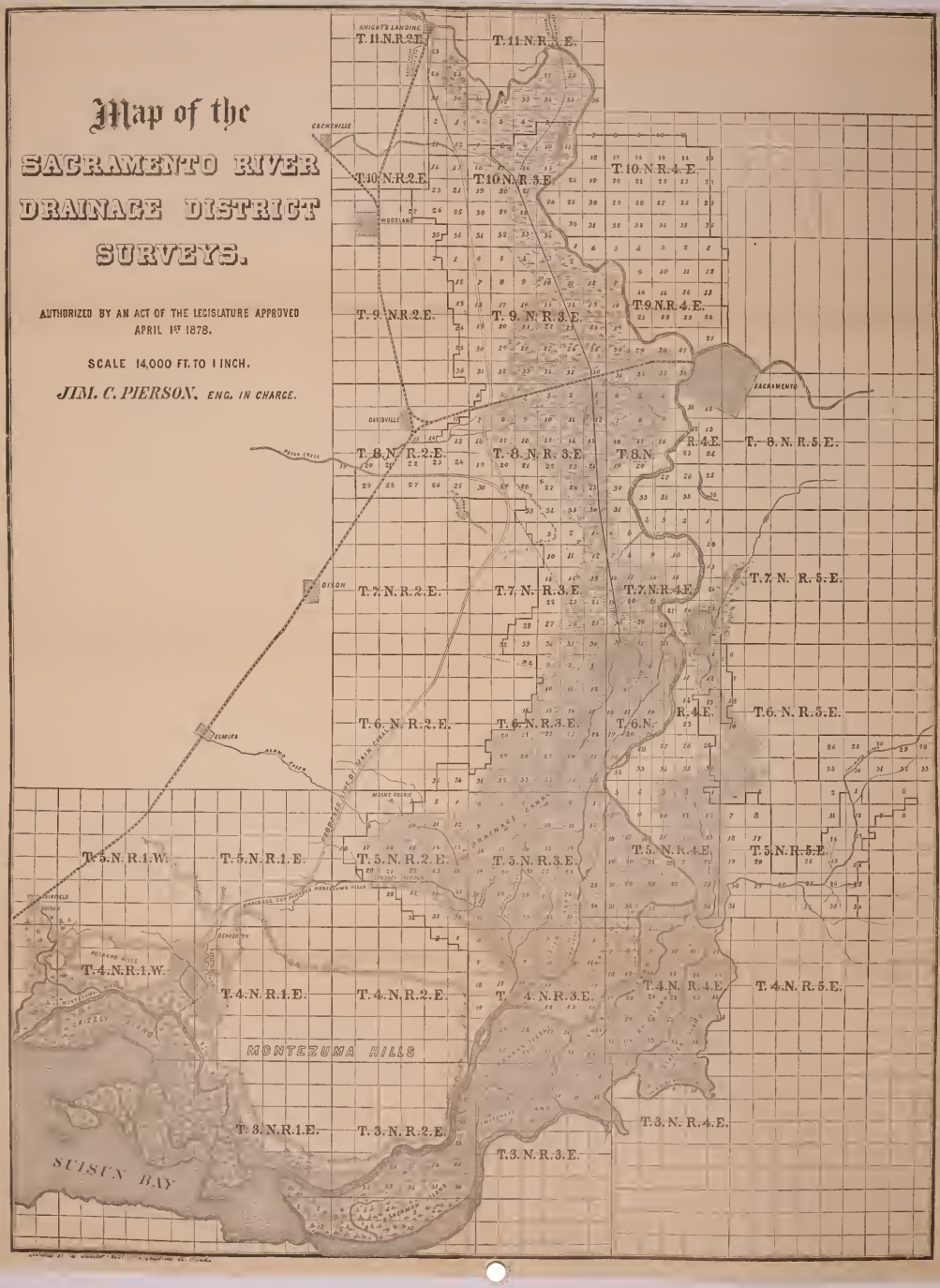
Map of the SACRAMENTO RIVER DRAINAGE DISTRICT SURVEYS.

AUTHORIZED BY AN ACT OF THE LEGISLATURE APPROVED APRIL 1ST 1878.

SCALE 14,000 FT. TO 1 INCH.

JIM. C. PIERSON. ENG. IN CHARGE.



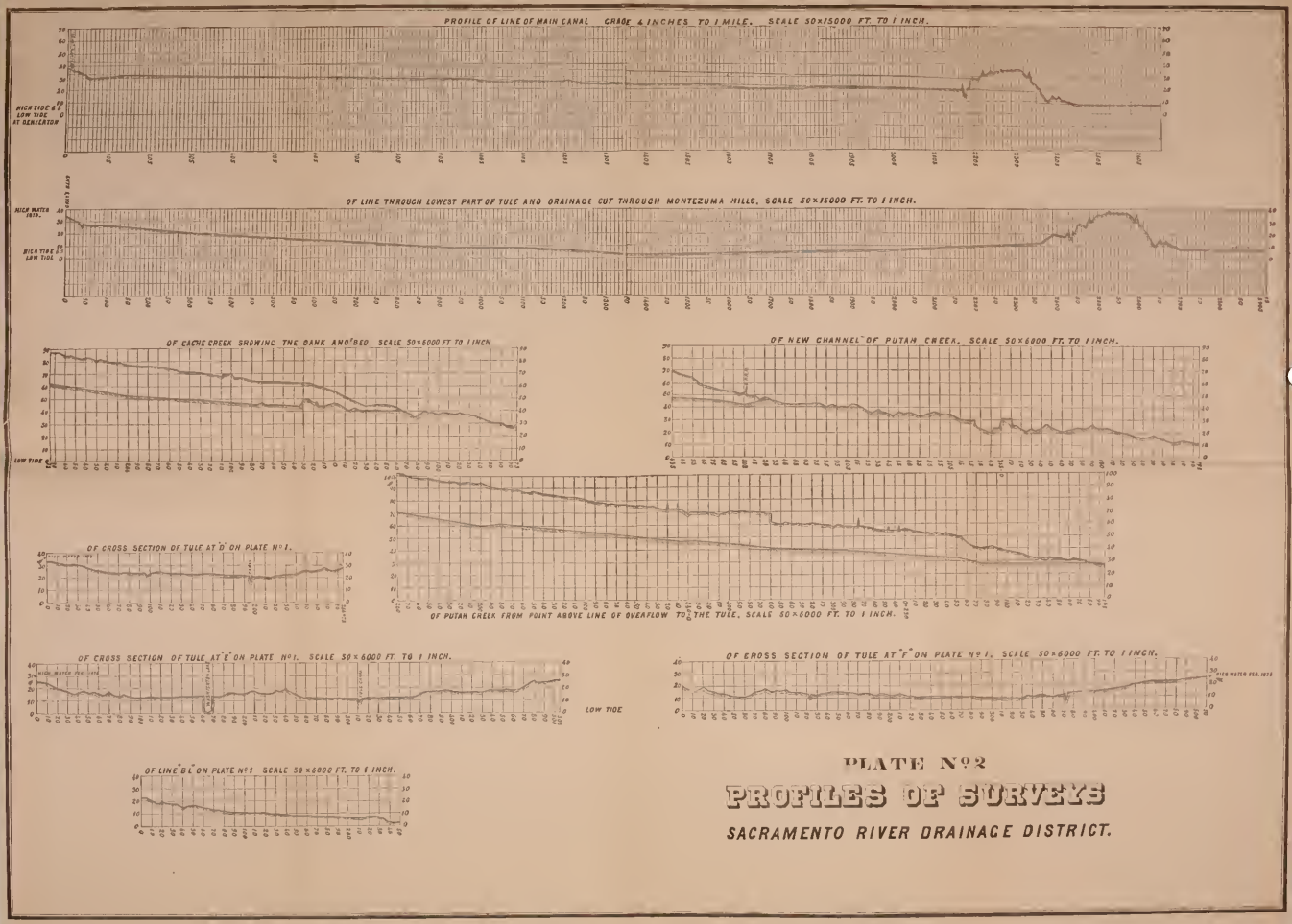


PLATE No 2

PROFILES OF SURVEYS

SACRAMENTO RIVER DRAINAGE DISTRICT.

COMMISSIONERS' REPORT.

OFFICE SACRAMENTO RIVER DRAINAGE DISTRICT,
SACRAMENTO, CALIFORNIA.

To His Excellency, William Irwin, Governor of California:

We, the undersigned, the Board of Commissioners of the Sacramento River Drainage District, a Board appointed in accordance with a provision of the Legislature of the State of California, at its last regular session, entitled "An Act creating the Sacramento River Drainage District, to inquire into the practicability of and the cost of constructing certain works described therein, for the purpose of draining the surplus water of the Sacramento River, and the waters flowing from the Coast Range of Mountains on the west, into the tule basin to the west of the Sacramento River, and south of Knight's Landing into Suisun Bay," do herewith submit the following report of action had under said Act:

The sum of $10,000 was appropriated by the Legislature out of the general funds of the State, and placed at our disposal for the purpose of making surveys and examinations to determine: first, the practicability of the certain works described in the Act; secondly, the effect the proposed works would have on the Sacramento River, Suisun Bay, and other navigable waters of the State; and thirdly, the cost of constructing said works.

THE BOARD ORGANIZED.

Agreeable to Section 2 of the Act, the Commissioners, after their appointments, organized, electing R. S. Carey, President, Christopher Green, Secretary, and appointing Isaac W. Smith, Chief Engineer, James C. Pierson, Assistant Engineer, on the 1st day of May, 1878.

ELECTION OF TREASURER.

Under Section 6 of the Act, and agreeable thereto, an election was held on the 6th day of July, 1878, for the purpose of electing a Treasurer, resulting in a tie vote. No further action was had pending the decision of the Board, who took the matter under advisement. The expense of such election was paid from the moneys of the fund hereinbefore mentioned.

SURVEYS COMMENCED.

Prior to June 1st, 1878, a surveying party, with James C. Pierson as Engineer in Charge, was organized, and placed in the field on June 1st, for the purpose of making the necessary surveys and examinations. Work was immediately commenced and unremittingly prosecuted up to the 5th day of November following, at which time the surveys were discontinued and the work of compiling the data thus obtained was commenced. Complete maps, plans, and estimates

were made and submitted, together with the report of Engineer Pierson of the work done, to the Board and Chief Engineer, the following June.

WORK DONE IN CONNECTION WITH THAT OF THE STATE ENGINEER AND THE UNITED STATES ENGINEER DEPARTMENT.

Inasmuch as the appropriation was inadequate to meet the expense of a complete examination of the Sacramento River in addition to other work necessary to be done, an agreement was entered into with the State Engineer, whereby he agreed, in consideration of the use and benefits of the information gained in our surveys and examinations, to furnish us all necessary data in regard to the Sacramento River that he might obtain. Such data was furnished and placed in the hands of Engineer Smith. We also received much information from Colonel G. H. Mendell, of the United States Engineer Department, who likewise received the benefits of a portion of our surveys. In this way we were enabled to obtain much valuable information not otherwise to have been obtained.

REPORT OF CHIEF ENGINEER.

The report of Isaac W. Smith, Chief Engineer to our Board, was submitted November 29th, 1879, and has been placed before the public through the medium of the Sacramento Record-Union. The report shows conclusively the impracticability of constructing the proposed works, and, therefore, agreeable to Section 3 of the Act, no further proceedings have been had. A copy of the report of the Engineers accompany this document. Copies have also been filed with the Secretary of State and the Surveyor-General.

THE MONEY EXPENDED.

The following is a recapitulation of the expenditures under Section 3 of the Act, vouchers in detail being on file in the State Controller's office:

For outfitting surveying party, for necessary running expenses of same, for office work, and for salaries	$9,581 65
Expenses attending the election of Treasurer	166 00
Expenses of reconnoisance party, consisting of the Governor, the Commissioners, the Engineers, and the Consulting Engineers	252 35
Total	$10,000 00

It may be well to remark here that the Commissioners and Secretary have received no compensation for their services or expenses, the Act providing that that be paid out of the Construction Fund, but as no such fund was created, owing to the adverse report of the Engineers, it will be necessary that further legislation shall be had in order to meet this demand. Also, that a portion of the services of the Engineers is still unpaid, owing to the fund becoming exhausted prior to the completion of their labors.

THE REPORTS OF THE ENGINEERS VERY COMPLETE.

The reports submitted by the Engineers are very complete in detail, and embrace an amount of valuable information, well compiled, that

has probably never been equaled by the expenditure of a like sum of money by the State, and we consider the State is well requited in the valuable information contained in the reports and maps accompanying the same.

RELIEF WORKS IN THE FUTURE.

The work done and the information gained while complete, so far as the requirements of the Act make it obligatory, is not sufficient to determine the practicability of other plans which may come before the people hereafter, and we, therefore, deem it of great importance that the work of making examinations be continued, and that the most searching and thorough examinations be made of that portion of the district embracing Cache Slough, the mouth of the Sacramento River, and those sloughs emptying into the San Joaquin and Mokelumne Rivers. This work is necessary, in order to complete and perfect the information so far gained in regard to this district.

RECOMMENDATIONS.

Inasmuch as the report of the Engineers is adverse to the construction of the works, as provided for in the Act, and as it demonstrates the futility of constructing any works of a relief nature in this district while such are exposed to the disastrous consequences which might follow relief measures undertaken by other districts, in the control of which we have no voice, we, therefore, recommend that no legislation be had with a view of constructing any works of this nature until such a time as a Board of competent engineers shall have examined into and reported on a scheme that shall embrace the question of relief and reclamation, with all its corollaries. Furthermore, as the mining debris in the Sacramento River and its tributaries forms an important factor in the consideration of all questions pertaining to a solution of this problem, and as such brings the interests of a large branch of the mining industries of the State in direct relation to those interests requiring relief and protection; and as the other districts are directly interested with this district in this and all questions of relief, although the latter receive direct nearly all the debris brought down by the Feather and American Rivers and their tributaries, and as, on account of this debris, the problem of improving the capacity of the Sacramento River is rendered more difficult, and is without a precedent; we, therefore, further recommend, that all the lowlands of the Sacramento Valley that need, or may need, reclamation or relief works be embraced in one district, under one control, that complete examinations may be undertaken to determine the most practicable and advantageous mode of relief of the whole; *provided*, the forthcoming report of the State Engineer does not already cover this ground, which is not to be expected, owing to the limited time he has had in which to make examinations adequate to a solution of this vast problem.

Respectfully submitted, this 15th day of December, A. D. 1879.

R. S. CAREY, President,
W. F. KNOX,
R. S. EGBERT,
Board of Commissioners.

CHRIS. GREEN, Secretary.

CHIEF ENGINEER'S REPORT.

CHIEF ENGINEER'S OFFICE, SACRAMENTO RIVER DRAINAGE DIST., }
SACRAMENTO, November 28th, 1879. }

The Board of Commissioners Sacramento River Drainage District:

GENTLEMEN: By the Act creating the Sacramento River Drainage District, it is made the duty of the Engineer or Engineers, to be appointed by you, to make a preliminary survey for the purpose of ascertaining the feasibility, effectiveness, and probable cost of the works defined in Section 1 of the Act, and, also, upon the completion of such survey, to make a full report thereof to your Board.

It is further provided "that if said Engineers shall report that, in their opinion, such proposed works are not feasible, or will not be reasonably effective for the purposes intended, or will cause material injury to Suisun Bay or other navigable waters of the State, or to any private lands, or that the probable cost thereof will exceed the amount of money for which bonds are authorized by the Act to be issued, then, and in that event, no further proceedings shall be had under the Act."

The report of the preliminary survey, with the details of the field work and the plans, sections, and calculations pertaining thereto, has been submitted to your Board under date of June 3d, 1879.

The report now submitted is with reference to the general results of the survey, and the conclusions deduced therefrom with regard to the feasibility, efficiency, and probable cost of the works proposed.

This report, by consent of your Board, has been deferred until certain data, now furnished, and necessary for the solution of the questions involved, could be obtained from the State Engineer.

THE OBJECT AND NATURE OF THE PROPOSED WORKS.

The object of the proposed works, as defined in the first section of the Act creating the drainage district, is to prevent overflow of the lands adjacent to the river, by "draining the surplus waters of the Sacramento River, and the waters flowing from the east side of the Coast Range of Mountains, in the counties of Yolo and Solano, into Suisun Bay."

It is provided in the same section that "said object shall be effected by the construction of the following works, to wit: A main canal, leading from the Sacramento River, at or near the place called Charleston, or Gray's Bend, in Yolo County, and running in a southerly and southwesterly direction to the basin of Nurse's Slough, in Solano County, and thence to Suisun Bay; the waters coming from the Coast Range of Mountains, from Cache Creek southerly, to be diverted and turned into said canal; also, in connection therewith, an auxiliary canal, if necessary, leading from the Sacramento River,

near the mouth of the American River, to said main canal; also, such auxiliary works as may be necessary for constructing or protecting said canals, or for rendering them effective."

THE PROPOSED CANAL NOT A DRAINAGE CANAL.

It may be here stated, to correct a popular misapprehension as to the object and nature of the proposed works, that the location of the main canal must depend on the hight of the head at junction with the river, and on the slope necessary to give a safe velocity to the current, with as light a cut as possible through the Montezuma Hills, and that the location of the canal cannot, therefore, under any circumstances, be at such level as to drain the tule lands on the west side of the river, nor is there any provision made to drain the waters from those lands in case of overflow.

THE AUXILIARY CANAL.

An auxiliary canal from the mouth of the American River to the junction with the main canal would be about ten miles in length, extending across the low tule lands on the west of the Sacramento, with levees from twelve to nineteen feet in hight.

In case of overflow from Cache Creek, or the Sacramento River above the mouth of the American, these levees would be either carried away or would dam up the waters as far as Knight's Landing, forming a deep lake, without drainage, over twenty miles in length and several miles in width.

The construction of the auxiliary canal would, therefore, in my opinion, be warranted only on the assumption that by means of the proposed works the waters of the Sacramento, and in the main canal, would always, and during all floods, be restrained within their banks, a result not likely to be attained by any system of works which may be devised.

Aside from the questions of cost and risk, there are other reasons which would render the construction of the auxiliary canal unadvisable and impracticable.

The difference in the flood-hights at the heads of the main and auxiliary canals is about eleven feet; the distance from the head of the main canal to the junction is about 22 miles, and from the junction to the head of the auxiliary canal, about 10 miles.

A grade of six inches to the mile, in the main canal, would, therefore, bring the point of junction on a level with the head of the auxiliary canal, and, in order to insure a proper fall to the latter, the main canal should have a fall of at least nine inches to the mile, increasing the cut through the Montezuma Hills to such an extent as to render the construction of the works practically impossible. The auxiliary canal may, therefore, be dismissed from consideration, and the proposed works will be limited to the main canal and the works necessary for its security and protection.

ON THE FEASIBILITY AND EFFECTIVENESS OF THE PROPOSED WORKS.

The purpose to be accomplished is the prevention of overflow, and in order that the proposed works may be feasible and effective for that purpose, it must be possible, with a reasonable assurance of

safety and permanence, and under circumstances now prevailing, or likely to prevail in the future, to accomplish the following results:

First—To divert and turn into the main canal the surplus waters of the Sacramento River.

Second—To divert and turn into the main canal the waters now draining from the Coast Range into the tule lands on the west of the river.

Third—To convey the waters turned into the main canal into Suisun Bay.

These three results are, in a measure, independent of each other, and will be considered separately.

THE DIVERSION OF THE SURPLUS WATERS OF THE SACRAMENTO RIVER INTO THE MAIN CANAL.

As regards the best disposition of surplus waters, whether by diversion or concentration within the channel of the stream, there exists a difference of opinion among authorities in hydraulic science.

By some it is maintained that at or near the time of maximum discharge the variation of velocity is sensibly equal to the variation of discharge; that, therefore, a large variation of flood-discharge, whether by reduction or increase, is attended by no sensible change of volume or hight, and that this fact, independently of other considerations, is sufficient to condemn all schemes for the improvement of rivers by the division of their waters into separate channels.

There are others who admit the undoubted fact that the surplus waters, if confined within the channel by raising the levees to a sufficient hight, would occupy a much less space than when diverted into a separate channel, but maintain that the comparative merits of the two systems cannot be settled by any general law, and must, in any particular case, be determined by considerations of practicability, cost, and security.

The discussion, in the present case, of the comparative merits of the concentration or diversion of flood-waters, for the prevention of inundation, would involve the consideration of what, under circumstances likely to occur in the future, would be the flood-hights and discharges at different sections of the river, and the hight and cost of the levees necessary for the prevention of overflow, questions which the data at my disposal do not enable me to decide, and on which I am not called upon to express an opinion.

If a report were required, not only on the feasibility and efficiency of the works proposed, but on the advisability of constructing them, under the conditions prescribed by law, and in advance of the forthcoming report of the State and Consulting Engineers, I should give it as my opinion that, to enable the owners of the land to be protected, and the capitalists who are expected to advance funds on the security of the lands, to judge intelligently on the merits of one system of works, they should be furnished with the data to enable them to understand whether the purpose in view might not be accomplished with greater certainty and at less cost under other systems, and that no action under the provisions of the Act creating the Sacramento River Drainage District would be advisable prior to a thorough investigation as to the system best adapted to the protection of all the lands bordering on the Sacramento River, considered as a connected whole, and not in independent parts. As, however, by the

terms of the law, this report must be confined to the absolute, rather than to the relative merits of the proposed system of works, such subjects only, will be considered as have a direct bearing on the questions proposed for solution.

THE AMOUNT OF THE SURPLUS WATERS OF THE SACRAMENTO RIVER.

Under the provisions of the Act creating the Sacramento River Drainage District it is proposed to construct, at or near Gray's Bend on that river, a permanent outlet, the discharge through which, under circumstances likely to occur in the future, will be sufficient to reduce the flood-discharge at all sections below the outlet to such extent as to afford a reasonable security against overflow, and, as no provision is made for raising the levees, the reduction of flood-discharge must be such that the flood-surface of the river will be confined to a safe distance below the line of the top of the levees as they now stand, or as they would stand if repaired and perfected to their present hight. To determine what, under any special conditions, would be the reduction of flood-discharge necessary to bring about the requisite reduction of flood-hights, it would be necessary to know the amount of the discharge to be reduced and the safe discharge to which it is to be reduced. The feasibility of the diversion of the surplus waters, and the effectiveness of the works proposed for that purpose, will depend on the amount of the requisite reduction of discharge, and the only practical method of calculating this amount is that adopted by Humphreys and Abbott for the purpose of determining the discharge through a proposed outlet at Bonnet-Carre Bend, which would reduce the flood-hights of the Mississippi River to a safe distance below the level of the top of the existing levees.

As a measure of the flood-discharges to be provided against in the future, the maximum discharge of the flood of 1858 was adopted.

The difference between the maximum discharges of 1858 and 1851, amounting to 150,000 cubic feet per second, was assumed as the reduction of the discharge necessary to reduce the flood-hights of 1858 to those of 1851.

The flood-surface of the river in 1851 stood 1 foot below the level of the top of the existing levees, and it was assumed that a further reduction of hight, to the amount of $3\frac{1}{10}$ feet, would be necessary for the stability of the banks and levees. The reduction of discharge, to reduce the hight $3\frac{1}{10}$ feet, was assumed, from experimental data, to be 150,000 cubic feet per second, making the total reduction of discharge 300,000 cubic feet per second, or over one-fourth of the maximum discharge of the river, and this amount was assumed also as the outlet discharge which would be necessary to produce the required reduction of the flood-discharge and surface hight, not only at the Bonnet-Carre Bend, but for "many miles above and below." The amount of the outlet discharge was so great as to warrant the opinion that the opening of an outlet of the requisite dimensions would not be advisable on account of the extent and costly character of the works for diverting and disposing of the surplus waters; the injury to the navigation of the lake into which the waters would be conducted; the great dimensions of the outlet and the impossibility of preventing the current from excavating the bed, although of clay from eighteen to twenty feet in thickness; and the danger that the outlet would ultimately become a main branch of the river, seriously impairing the navigation at its present mouth.

The general conclusion reached by Humphreys and Abbott, with regard to outlets, as a means of protection against floods on the Mississippi River, was to the effect that they "are of great utility, as far as the river is concerned, but are virtually impracticable from the difficulty of disposing of the water," and that their observations demonstrated "with all the certainty of which the subject is capable, the disastrous consequences that must follow the resort to this means of protection."

The opinion as regards the advantages to the Mississippi are, however, based on conditions which do not exist in the case of the Sacramento, and the great utility of an outlet, so far as any river is concerned, may be doubted in a case like that above cited, where the amount of the surplus water is so great that there would be danger that the outlet would become a main branch of the river, and seriously impair the navigation at its present mouth.

THE AMOUNT OF THE SURPLUS WATERS OF THE SACRAMENTO RIVER DURING THE FLOOD OF MARCH, 1879.

The only data concerning the discharge of the Sacramento River are the measurements by the State Engineer, during the flood of the past year, and the amount of the surplus waters during that flood is the only basis for an estimate of what will be the amount under circumstances likely to occur in the future.

The elevations of the top of the levees above the flood-surface of the river, at different points, from Butte City, 173 miles above New York Landing, to Collinsville, near the mouth of the river, were as follows:

At Butte City	1.9 feet.
At Princeton	2.0 feet.
At Colusa	2.2 feet.
At Butte Slough	2.3 feet.
At Meridan	1.5 feet.
At Winn's Landing	1.0 feet.
At Gray's Bend	2.6 feet.
At mouth of Feather River	1.6 feet.
At break above Gray and Shaw's	1.9 feet.
At Sacramento City	2.5 feet.
At Clarksburg	2.9 feet.
At Collinsville	1.6 feet.

As the levees are practically adapted to the flood-hights of the river, these elevations illustrate the fact that, within certain limits, a safe discharge at one section is attended with a safe discharge at all others, although the amount of those discharges may be very different, but it is customary to assume that under a safe discharge the water surface will be at least three feet below the level of the levees.

The distances from Colusa to points named below are as follows:

To Knight's Landing	56 miles.
To Gray's Bend	60 miles.
To mouth of Feather River	70 miles.
To Gray and Shaw's Station	75 miles.
To mouth of American River	90 miles.
To Sacramento City	91 miles.
To Freeport	104 miles.
To Rio Vista	132 miles.

Knight's Landing is at the upper limit of the Sacramento River Drainage District, and, for reasons hereinafter stated, is the proper point for the proposed outlet.

During the March flood of 1879 a large portion of the flood-waters of the upper river and its tributaries discharged into an immense basin east of the Sacramento and between that river and the Feather, and flowing through that basin were returned, with the waters of the Feather, into the Sacramento River.

Knight's Landing is on a ridge of land which intercepts and turns into the river all the waters on the western side, and hence the whole of the flood-waters of the upper rivers were returned into the channel between Knight's Landing and the mouth of Feather River.

A large portion of these waters were again diverted through crevasses, between Knight's Landing and Freeport, into the tule basin on the west of the river, and, with the waters of Cache, Putah, and other streams from the Coast Range, were discharged through that basin and Cache Slough into the river above Rio Vista.

As none of the waters escaped below Feather River on the eastern side of the Sacramento, the whole of the flood-waters of the river were discharged either through the channel at Freeport, thirteen miles below Sacramento City, or through crevasses opening into the tule basin on the western side, between Knight's Landing and Freeport.

If, therefore, the surplus waters of the river during any flood are those which cannot be confined to a safe distance below the top of the levees, and during the March flood of 1879 the discharge through the channel could not have been safely increased, the crevasse discharge between Knight's Landing and Freeport may be assumed as the measure of the surplus waters, under the special conditions of that flood.

The amount of the crevasse discharge between Knight's Landing and Freeport Station may be estimated as follows:

The maximum discharge through the tule basin was measured under the piling of the California Pacific Railroad, which extends from Sacramento City westward across the basin.

This discharge amounts to 66,000 cubic feet per second, and the whole of the water was from Cache Creek, and from the crevasses between Knight's Landing and Sacramento City.

The maximum discharge of Cache Creek occurred on the 5th of March, seven days before the maximum discharge under the railroad pilings, and eight days before the maximum discharge at Freeport, and was calculated from the measured area of the high water section, the wet perimeter and the slope of the bed. By Jackson's formula it amounted to 35,000 cubic feet per second, and by the ordinary formula to over 40,000 cubic feet. It was estimated, approximately, by the State Engineer, at 34,000 cubic feet, from independent data.

Assuming the maximum discharge of Cache Creek at 35,000 cubic feet per second, and that the maximum discharge under the railroad pilings could not have exceeded the sum of the maximum discharges from Cache Creek and from the crevasses between Knight's Landing and Sacramento City, the latter discharge was at least 31,000 cubic feet per second, and as Cache Creek rises and falls very rapidly, it is probable that the crevasse discharge was over 40,000 cubic feet, a result which may be checked by an independent method of calculation based on the following premises:

The amount of the maximum discharge at a lower section of a stream, at any given time, will depend not only on the discharges at that time at different points above, but on the positions of the outlets and inlets, and the velocities of transmission and the times of arrival of the flood-waves from the different sources of supply.

When, however, the discharges are all uniform for a period of time sufficient for their transmission between the extreme points of discharge, the discharge, at a given time, at the lowest point, will be nearly the difference between the sums of the discharges, at that time, of the outlets and tributaries above. During the March flood of 1879 current measurements were made at four points on the river, and the maximum discharges at those points were as follows, in cubic feet per second:

At Colusa	62,000
At Knight's Landing	23,000
At Gray and Shaw's	66,000
At Freeport	69,400

The Freeport maximum discharge occurred on the 13th of March, and the water was supplied through the channel at Knight's Landing, and from the Feather and American Rivers and basins.

The discharges from these sources on the 13th day of March were as follows, in cubic feet per second:

From Knight's Landing	19,500
From Feather River and basin	65,800
From American River and basin	31,000
Total	116,300

The discharge at Knight's Landing is from actual measurement, and the discharges from the Feather and American Rivers and basins from measurements, or estimates based on measurements, by the State Engineer.

The gauge readings at Knight's Landing, Gray, and Shaw's, and Freeport, did not vary $\frac{3}{10}$ of a foot from the 11th to the 14th of March, and the discharges at those points were, therefore, practically uniform during that period.

Assuming that no new crevasses were opened or increased about the 13th of March, the crevasse discharge was uniform, because the hight of the adjacent river surface did not change.

As the river discharge at Gray and Shaw's, below Feather River, and at Freeport, below the American River, remained constant for several days, no great change of discharge could have occurred either from Feather River and basin or American River and basin.

Under these assumptions the discharge at Freeport would have been 116,300 cubic feet per second, had there been no crevasse discharge, and as the actual measured discharge was 69,400 cubic feet, the crevasse discharge was 46,900 cubic feet per second.

The result in the former estimate would have been the same, by assuming the Cache Creek discharge at 19,100 cubic feet per second.

The discharge from crevasses between Gray and Shaw's and Freeport may be estimated in a similar manner.

The water flowing through the channel at Freeport, March 13th, was from the channel at Gray and Shaw's, 29 miles above, and from the American River and basin, 15 miles above Freeport.

If no water had escaped through crevasses below Gray and Shaw's, the Freeport discharge would have been as follows, in cubic feet per second:

From Gray and Shaw's (gauged)	60,500
From American River and basin	30,900
Total	91,400
The actual discharge was	69,400

The crevasse discharge between Gray and Shaw's and Freeport was, therefore, 22,000 cubic feet per second.

These estimates are based on data which may be, to some extent, incorrect, but they are sufficient to warrant the opinion that the crevasse discharge between Knight's Landing and Freeport, during the flood of March, 1879, was at least 30,000, and probably over 40,000 cubic feet per second, and it is sufficient for all the purposes of this report to assume it at the former figure.

Supposing, however, the crevasse closed, and the crevasse discharge concentrated through an outlet at Knight's Landing, would the safe discharge of the channel below and the amount of the surplus waters have remained the same?

As the flood-surface of the river was on a stand for several days, it may be assumed, with sufficient accuracy, that each outlet reduced the discharge of the river below by an amount equal to the outlet discharge.

If, therefore, the whole crevasse discharge had been concentrated through one outlet at Knight's Landing, the reduction of discharge would have been the same at sections below the lowest crevasse, but greater at sections above, and the effect on the height of the lower sections at least nearly the same.

At sections near Gray's Bend the reduction of discharge would be much greater, but such reduction could not have its normal effect in reducing the depth, unless a corresponding reduction of the flood-hight should take place below.

The maximum discharge, for instance, at Knight's Landing, was reduced over 50 per cent. by the crevasse discharge above, yet the flood-hight was but little affected on account of the hight of the river at the mouth of Feather, due to the largely increased discharge at that point.

It must also be considered that if all the crevasses from Knight's Landing to the mouth of Feather had been closed, the discharge below the mouth would not probably have exceeded 80,000 cubic feet per second, and the reduction of this discharge by 30,000 cubic feet would, for reasons hereafter stated, have resulted in an elevation of the bed which might have neutralized the effect of any diminution of depth which might have followed the diminution of discharge.

The crevasse discharge of the river below Knight's Landing may, therefore, be assumed as the measure of an outlet-discharge at that point, which would have been necessary to have maintained the flood-surface of the river at from 1½ feet to 2 feet below the top of the levees during the March flood of 1879.

THE AMOUNT OF THE SURPLUS WATERS OF THE SACRAMENTO RIVER DURING THE FLOOD OF 1878.

No measurements of discharge were made during this flood, but the flood-surface stood, at a point near Freeport, $1\frac{6}{10}$ feet higher than during the flood of 1879.

At Freeport during the latter flood an increase of 5,000 cubic feet per second caused a rise of 1 foot near the time of high water, and the flood-discharge at Freeport during the flood of 1878 may, therefore, be assumed at 8,000 cubic feet per seeond greater than that of 1879.

The amount of water running through the tule basin on the west of the river was greater than in 1879, and caused great damage to the railroad embankments as well as to private property.

If this increase of discharge through the tules, due to the crevasse discharge from the rivers, be assumed at 6,000 cubic feet per second greater than in 1879, the surplus waters in 1878 would have been 14,000 cubic feet per second greater than in the flood of 1879, or at least 45,000 cubic feet per second.

THE AMOUNT OF THE SURPLUS WATERS UNDER DISCHARGES LIKELY TO OCCUR IN THE FUTURE.

The amount of the maximum discharge, and of the surplus waters of the river, will depend upon circumstances which cannot, at the present time, be foreseen or controlled; but it is certain that, under conditions which may probably occur, this discharge may be largely increased.

The Sacramento, Feather, and American Rivers, at high water stages, now communicate directly with immense reservoir basins, which under ordinary circumstances hold back the flood-waters and modify and reduce the flood-discharges.

At high water of the flood of 1879 the contents of the basin between the Feather and upper Sacramento Rivers amounted to 45,000,000,000 cubic feet, and those of the American River to over 17,500,000,000.

With a flow of 40,000 cubic feet per second, thirteeen days would be required to fill the former and five days for the latter. During the flood of March, 1879, the maximum discharge at Colusa, on the main Sacramento, was 62,000 cubic feet per second, and at Knight's Landing, 56 miles below, but 23,000 cubic feet, this great reduction being due to the diversion of a large portion of the flood-waters into the Feather River basin.

A portion of these waters, and of those of the Feather and other tributaries, are held back, and the remainder discharged into the Sacramento near the mouth of the Feather, and this basin and that of the American River exert an important influence on the maximum discharge of the river below.

If all the waters of the Sacramento and its tributaries should be confined within their channels, by raising the levees to a sufficient hight, the flood-discharge on Gray's Bend would be more than doubled, and at other sections largely increased. The amount of this increase, under the conditions likely to occur in the future, will be considered in the forthcoming report of the State Engineer, to whom I am indebted for all of the data used in the foregoing discussion.

The facts stated above are sufficient to warrant the opinion that with regard to any works which may be now constructed to divert the surplus waters of the Sacramento, under circumstances likely to occur hereafter, they may be either insufficient for the purpose intended, or must be planned at great cost to meet difficulties which may never arise.

THE POSSIBILITY OF THE DIVERSION OF THE SURPLUS WATERS OF THE SACRAMENTO THROUGH AN OUTLET AT OR NEAR GRAY'S BEND.

The maximum discharge at Knight's Landing, near Gray's Bend, during the March flood of 1879, was but 23,000 cubic feet per second, and would be less, should the flood be caused by a rise of the American and Feather Rivers.

Estimating the surplus waters of the rivers even at 30,000 cubic feet per second, they would exceed the whole flow of the river adjacent to the proposed outlet, and to effect the proposed diversion, a portion of the discharge must be taken from the river below the mouth of the Feather, producing an up-stream current, and necessitating a low water instead of a high water outlet; but even supposing the proposed diversion possible, the elevation of the bed at the mouth of the Feather, and below, might neutralize the depression of the surface due to the reduced discharge.

It is maintained by Humphreys and Abbott, in their report on the Mississippi River, that no elevation of the bed from deposit of materials can ever occur in that river below a practicable high water outlet, because the waters are never charged to their full capacity with suspended matter, and the maximum power of the current for transporting the materials along the bottom is never called into requisition. The case is, however, very different in the Sacramento River.

The waters of the main Sacramento are comparatively clear, but the debris from the hydraulic mines on the upper waters of the American and Feather Rivers is accumulated during the low water season, and the flood-wave of the waters, surcharged with suspended matter, is accompanied by a wave of materials transported along the bottom, so that at many points the elevation of the bed is greatest at the time of highest water, both in the upper and lower rivers, as is shown by sections and measurements made by Colonel Mendell, of the United States Engineer Corps, and by the State Engineer.

The flood-waters of the Feather and American Rivers being now surcharged with suspended matter, the diversion of the clear waters from the Sacramento, and the reduction of velocity at points below the outlet, would diminish the capacity of suspension and of transporting the materials along the bottom, and would cause an elevation of the bed at the precise stage of water when such elevation might be attended with the most disastrous consequences.

OPINION AS TO THE POSSIBILITY OF DIVERTING THE SURPLUS WATERS OF THE SACRAMENTO INTO THE PROPOSED MAIN CANAL.

It has been shown that the amount of the surplus waters was at least 30,000 cubic feet per second during the flood of 1879, and greater during that of the preceding year; and that, under circumstances which may probably occur in the future, it may be largely increased.

And I am of opinion, for the reasons stated above, that the proposed diversion cannot be accomplished by an outlet at Gray's Bend, or elsewhere, even under the conditions of such a flood as that of March, 1879.

THE DIVERSION INTO THE MAIN CANAL OF THE WATERS FROM THE COAST RANGE, ON THE WEST OF THE SACRAMENTO VALLEY.

The question now to be considered is, whether these waters can be safely conducted *into*, not *through*, the main canal, the possibility of conducting them safely to Suisun Bay being a subject of after consideration.

It is characteristic of all the streams, large and small, from the Coast Range on the west of the Sacramento Valley, that owing to their steep slopes and the rapid drainage of the rain-fall they bring down to the margin of the foot-hills large quantities of materials, with which they build out their beds and channels into the valley, on tongues of land elevated above the level of the adjacent country.

As the elevation of the beds increases the slope and velocity diminish, and the volume of the water increases until the stream is diverted into another channel, and the same process is again commenced.

The principal streams flowing into the tule basin are Cache and Putah Creeks. Cache Creek formerly emptied into the Sacramento River at Knight's Landing, the old bed being still visible at that point. The tongue or ridge of land at that point, which now divides the upper and lower tule basins on the west of the river, was doubtless formed from deposits from Cache Creek, which now sinks into the tules 5 miles to the south and 10 feet below the level of its former banks. The average fall of the present bed, from a point 6½ miles above its junction with the proposed line of the main canal, is over 4 feet to the mile.

The area of the high water section March 5th, 1879, at that point, was 3,558 square feet; the mean depth, $23\frac{25}{100}$ feet; the slope of the bed 1 foot in 1,000; the mean velocity, from these data by Jackson's formula, 10 feet per second, or about 7 miles per hour, and the discharge 35,000 cubic feet per second.

This discharge was estimated from other formula, with the same data, by Mr. Pierson, at 40,600 cubic feet per second, and by the State Engineers, from independent data, approximately, at 34,000 cubic feet.

Putah Creek, at one time, discharged into the tules, about 4 miles south and 5 miles east of its present channel, the tongue of land formed by the deposited materials extending to within 3 miles of the Sacramento River, the width of the tongue, judging from the contour line of the main canal, being over 2½ miles.

From a point 11½ miles above the intersection of the present channel with the line of the main canal, the average slope is over 4 feet to the mile.

At that point the flood-waters are all confined within the banks; the area of the high water section March 5th, 1879, was 5,750 square feet; the main depth, $30\frac{5}{10}$ feet; the wet perimeter 274 feet, and the slope of the bed 1 foot in a thousand.

The measured surface velocity, $5\frac{8}{10}$ feet below high-water, was $12\frac{8}{10}$ feet, and the mean, estimated at $\frac{82}{100}$ of the surface velocity, was $10\frac{5}{10}$ feet per second.

The high water mean velocity, estimated by Jackson's formula, was $11\frac{3}{10}$ feet per second, or over 8 miles per hour, and the maximum discharge 65,000 cubic feet per second.

This discharge was estimated by Mr. Pierson, from the same data, at 77,000 cubic feet per second, or 8,000 cubic feet more than the maximum channel discharge of the river at Freeport, below Sacramento City.

In order that the materials brought down by these streams may not cause a continual elevation of their beds, their velocities must be such as to carry down the materials into the main canal, and the velocity of the main canal must be sufficient to transport the materials from the creeks into Suisun Bay, a result which in neither case can possibly be accomplished, because any increase of the velocity of the creeks, from confinement within the levees, would only result in bringing down the coarser materials still nearer the line of the canal; and as the slope of the canal cannot, without increasing the cut through the Montezuma Hills to an impracticable extent, be more than 4 inches to the mile, it cannot carry off the materials brought down from the beds of the creeks with a slope of over 4 feet to the mile.

I am, therefore, of the opinion that the waters of Putah and Cache Creeks cannot be safely conveyed into the main canal, because of the continuous elevation of the bed of the creeks, and the danger to the levees of the main canal at their mouths.

THE DRAINAGE THROUGH THE MAIN CANAL INTO SUISUN BAY OF THE SURPLUS WATERS OF THE SACRAMENTO AND THE WATERS FROM THE EASTERN SLOPE OF THE COAST RANGE.

On this subject it would not be necessary to speak were it not for the possibility that an intercepting canal may be proposed hereafter under other conditions.

The difficulty in this case arises not so much from the cost and risk of conveying each stream separately into Suisun Bay, but because the waters from the Coast Range, and the surplus waters of the river, must all be carried through the same canal.

The case is very different from the junction of a main stream with its tributaries, for the upper portion of the canal might in some cases be dry at the time of the flood-discharges of Putah and Cache Creeks, and the waters from those creeks would, for a time, run both toward the Sacramento River and Suisun Bay, thus causing a deposit of the materials brought down from the Coast Range.

Independently of this consideration the comparative velocities of the streams from the Coast Range, and of the main canal, is such that the latter can never transport the materials brought into it, and the bed must, therefore, rise until the hight of the waters is such as to overflow the levees, and this same objection will, in my opinion, apply to the construction of any canal with a view to intercept and turn the waters of the Coast Range from the present channels.

In the case of small canals and mining ditches, the sediment may be discharged through waste-gates, but this could not be effected in larger canals, unless at great expense and risk.

COST OF PROPOSED WORKS.

By the terms of the law the cost must not exceed $5 per acre on the lands within the district. The number of acres within the district is as follows:

In Sacramento County	166,121.80
In Solano County	49,281.86
In Yolo County	147,065.32
Total	362,468.98

Limit of cost at $5 per acre, $1,812,344 90.

The main canal was located under the following considerations:

The construction of the main canal from Gray's Bend would necessitate the building of high levees across the low tule lands west of that point, and in case of overflow from above these levees would dam up the waters and could not be protected from the action of the wind and waves, unless at great risk and expense.

The canal should, therefore, commence at Knight's Landing, and be conducted along the south slope of the ridge at that point to the firm ground on the west of the tules.

High water at Knight's Landing is 35 feet above ordinary high tide at Denverton, at the head of Suisun Bay, and 4½ feet above the summit of the Montezuma Hills.

The distance by the course of the canal from Knight's Landing to the summit is 43 miles, and to Denverton 46 miles.

Assuming the bed of the canal to fall from 8 feet below high water at Knight's Landing to ordinary high tide at Denverton, the slope would be 7 inches to the mile, and the cut at the summit of the Montezuma Hills over 28 feet, which would be impracticable on account of the cost.

A slope of 4 inches to the mile would give a summit cut of 18 feet, and a fall to high tide at Denverton of nearly 13 feet in 3 miles, which is so great that an overfall of 10 feet would be necessary for the security of the sides of the cut.

The following estimate is made on the basis of a slope of 4 inches to the mile from Knight's Landing to the cut through the Montezuma Hills, and 6 inches through the cut to Denverton; the levees sloping 3 horizontally to 1 vertically on the inside, and 2 to 1 on the outside; 9 feet above grade and 5 feet in width on the top; the cut 600 feet in width at bottom, and with side slopes of 45°.

Such a cut would not have the dimensions to carry off the waters which might be delivered from above, because, with water 10 feet deep and flowing at the rate of 7 miles per hour, the discharge would be but 62,000 cubic feet per second, while the discharge from Putah and Cache Creeks alone, at high water, is over 100,000 cubic feet.

It has not, however, been deemed necessary to calculate the dimensions and slopes for any particular discharge, because, as will be shown, the cost, under the most favorable conditions, will exceed the limit prescribed by law.

The following is an estimate of the excavation and embankment which would be required under the above-mentioned conditions for the main canal from Knight's Landing to Denverton, and for the connections with Putah and Cache Creeks.

	Miles.	Excavation, cubic yards.	Embankment, cubic yards.
Main canal	1.04	302,739	
Main canal	40.36		4,576,569
Main canal	4.70	6,269,259	
Main canal	46.10	6,571,998	4,576,569
Cache Creek	4.55		310,146
Cache Creek	2.57	458,835	
Putah Creek	12.36		1,069,334
Totals	65.58	7,030,833	5,956,049

Borings to high tide level through the Montezuma Hills demonstrate the fact that there is a narrow ridge of soft sandstone towards the southern margin, which is rather an advantage in case it should be necessary to construct an overflow of 10 feet.

The material of the hills can be easily excavated, but will require a greater side slope than is assumed in this estimate.

The material north of the Montezuma Hills is well adapted for levees.

The cost, including expenses of supervision and contingencies, I estimate at 15 cents for levees and 25 cents per yard for excavation. At these prices the cost of the main canal and auxiliary canals at Cache and Putah Creeks will be as follows, as shown in detail in report of June 3d, 1879:

Excavation—7,030,833 cubic yards at 25 cents	$1,757,708 00
Embankment—5,956,049 cubic yards at 15 cents	893,407 00
Total	$2,651,115 00
Limit of cost by law	1,812,345 00
Excess	$838,770 00

This cost is estimated for the canals from Knight's Landing to Denverton, not including cost of head-works, overfalls, and auxiliary canals for conducting the smaller streams into the main canal, or cost of right of way.

To continue the canal from Denverton across the tules to Montezuma Slough, a distance of $4\frac{3}{10}$ miles, would require 2,214,000 cubic yards of levee, which, at 15 cents per yard, would cost $332,000.

In my opinion it would cost less to purchase the tule lands between Denverton and Montezuma Slough, and build a low levee along the margin of the tules for protection against back-water during floods.

The cost of the works would, therefore, in my opinion, even under the most favorable assumptions, exceed, by over $1,000,000, the limit prescribed by law.

THE PRACTICABILITY AND COST OF DRAINING THE TULE BASIN ON THE WEST OF THE SACRAMENTO INTO SUISUN BAY BY MEANS OF A CANAL THROUGH THE MONTEZUMA HILLS.

By request of your Board I present at the conclusion of my report my opinions with regard to a tidal drainage canal through the Montezuma Hills, based on such information as could be obtained during

the progress of the preliminary surveys of the Sacramento River Drainage District.

Under present circumstances all of the escaped flood-waters of the river below Knight's Landing, with those of Putah, Cache, and other creeks from the eastern slope of the Coast Range, flow into the tule basin on the west of the river, and when the surface level of the accumulated waters rises above that of the river surface, they flow into the river through Cache Slough, along the northern base of the Montezuma Hills.

During the flood of 1878, the high water surface at the southern limit of the basin was 15 inches higher than the flood-surface of the river at the mouth of Cache Slough, and the discharge through that slough, across the river current, banked up the waters of the river, and was the cause of great damage to the levees of the islands lying between the Sacramento and San Joaquin Rivers.

The construction of a drainage canal into Suisun Bay would lower the level of the waters within the basin, and necessitate the building of levees across Cache Slough, to prevent the inflow of waters from the river, and the discharge through the drainage canal, in conjunction with the storage capacity of the basin, should be sufficient to prevent such rise of the waters as would endanger the river levees near the mouth of Cache Slough or elsewhere.

The cost and dimensions of the canal must, therefore, depend on the reservoir capacity of the basin and the amount of the waters to be drained into Suisun Bay.

THE RESERVOIR CAPACITY OF THE TULE BASIN.

In order to determine the cubic contents of the basin, sections were taken at several points, and also the elevations of the flood-surface in the spring of 1878.

From these sections and elevations it is estimated that the cubic contents of the basin, at high water of 1878, amounted to 49,000,000,000 cubic feet, about 4,000,000,000 more than the contents of the Feather River basin at high water of March, 1879.

For the protection of the lands within the basin, as well as for the security of the river levees, the waters of the basin should not be allowed to rise within 3 feet of the level of the flood of 1878, and in such case, and at such level, the cubic contents of the basin would be 32,000,000,000 cubic feet.

These calculations were made from the hight of the flood-surface of the water above the lowest line of the tules, as shown on the profile in Sheet No. 2, accompanying this report, and from the assumed width of the surface at the different sections, and the estimate of the cubic contents is, therefore, only approximate, although sufficiently accurate for the purposes of this report.

THE AMOUNT OF THE WATERS TO BE DRAINED FROM THE TULE BASIN INTO SUISUN BAY.

During the flood of 1879 the maximum discharge from Putah and Cache Creeks into the basin was about 100,000 cubic feet per second, and from the river, through crevasses, over 30,000 cubic feet.

The discharge from Putah and Cache Creeks diminished very rapidly, but the river stood at a high stage for nearly a month.

During the flood of 1878 the maximum discharge from Putah and Cache Creeks was not so great, but the crevasse discharge from the river and the discharge through the tule basin was much greater.

If it be assumed that for eighteen and a half days the average flow into the basin would be 40,000 cubic feet per second, it would be sufficient to fill the basin twice over to 3 feet below the level of the flood of 1878, and in order that the waters might not rise beyond that hight, it would be necessary that the average discharge of the canal for eighteen and a half days should be 20,000 cubic feet per second.

The basin once filled, however, the reservoir capacity of the basin ceases to reduce the discharge from the lower end, which must then be equal to the whole discharge through the basin.

By reference to the profile on Plate No. II, accompanying this report, it will be seen that the length of a line along the lowest part of the tules is 44 miles, and the average slope of the bed over 5 inches to the mile; the depth along this line during the flood of 1878 was, on an average, over 10 feet, and the width of the flood-surface from 4 to 8 miles.

Supposing the width of a section 20,000 feet, the average depth 6 feet, and the slope 6 inches to the mile, the mean velocity in an ordinary channel would be about 2¼ feet per second.

The velocity of the current is, however, checked by the resistance from the tules; but putting it even at 1 foot per second, the discharge would be 120,000 cubic feet per second.

The measured maximum discharge during the flood of 1879 was over 130,000 cubic feet, of which 100,000 was from Putah and Cache Creeks.

During the flood of 1878 it is probable that the maximum discharge was over 150,000 cubic feet per second, more than double the channel discharge of the river at Freeport.

Putah and Cache Creeks rise and fall very rapidly, but one day of maximum discharge would be equivalent to an average discharge of 10,000 cubic feet for ten days.

The duration of floods in the river is so great that the crevasse discharge may continue approximately uniform for a sufficient period to fill the basin thrice over.

From these figures some idea may be formed of the immense mass of flood-waters poured through Cache Slough across the channel of the river.

Should this outlet be closed, the capacity of a drainage canal which will divert into Suisun Bay the waters of Putah and Cache Creeks, and the surplus waters of the river, under the present system of levees, must, in my opinion, far exceed 20,000 cubic feet per second.

It may be suggested that a moderate canal discharge would, at least, drain the waters of the basin so that crops might be put in within ninety or one hundred days after the time of high water.

Supposing, for instance, the basin filled to the flood-hight of 1878, a canal discharge of 5,600 cubic feet per second would drain off the waters in about one hundred days.

Such discharge would not, however, prevent, even during ordinary floods, the filling of the basin, the destruction of the river levees, and the inflow of the river waters, in which case the subsidence of the waters within the basin would depend on the subsidence of the waters of the river.

COST AND DIMENSIONS OF A CANAL FOR DIFFERENT DISCHARGES.

It is proposed to cut the bed of the canal to the level of ordinary high tide at Denverton, at the head of Suisun Bay. This level is but 10 feet below the flood-hight of the waters of the basin during the flood of 1878, and 8¾ feet below the flood-hight of the river at the mouth of Cache Slough, and in order that the water at the entrance to the canal may not rise to within 1¾ feet of the flood-hight of the river in 1878, the depth of water in the channel cannot exceed 7 feet.

The distance through the cut from the northern base of the Montezuma Hills to the tules of Suisun Bay, at the level of ordinary high tide, is about 7 miles, and even assuming that the current would ultimately cut the bed so that the water-surface would fall to the high tide level at Denverton, the slope could not exceed 1 foot to the mile. With this slope, a depth of 7 feet and a width of bed of 200 feet, the discharge would be about 5,000 cubic feet per second.

The amount of excavation, as shown in the detailed calculations accompanying this report, would be 4,630,000 cubic yards, and the cost, at 25 cents per yard, $1,157,500.

A canal with a bed of 1,000 feet, under the same conditons, would discharge about 23,000 cubic feet per second, and would cost $5,335,000.

This would not include the right of way, or the levees at and beyond Denverton, or the auxiliary works and canals for conducting the waters from the basin to the entrance of the canal, and including these items, and also the cost of supervision and contingencies, the cost of a canal with a maximum capacity of 23,000 cubic feet per second would not be less than $6,000,000.

These calculations assume the depth of water in the channel at 7 feet, but with a depth of 4 feet the discharge for a width of 1,000 feet would be about 10,000 cubic feet per second.

Should a levee system be perfected which would afford a reasonable security against overflow, it would be possible to drain the waters of Putah and Cache Creeks into Suisun Bay by means of a canal of moderate dimensions, but its construction would not be advisable under present circumstances. The construction of a drainage canal of sufficient capacity to divert into Suisun Bay the waters now discharged during floods through Cache Slough across the channel of the Sacramento would, in my opinion, be of great benefit to the river, above and below; would protect the levees of the island between the Sacramento and the San Joaquin, and would reclaim a large portion of the lands within the tule basin on the west of the river.

The work would, however, on account of the heavy cutting, the limited depth of water, and the great width of the channel necessary in order to secure the requisite capacity of discharge, be of such magnitude and cost, that it could be executed only as a part of a general plan and in connection with, and subsequent to, a system of levees affording a reasonable security against inundation, at least during ordinary floods.

Respectfully submitted,

ISAAC W. SMITH,
Chief Engineer Sacramento River Drainage District.

REPORT OF THE ENGINEER IN CHARGE.

As Engineer in Charge of the work done by the Sacramento River Drainage District, under an Act of the Legislature, entitled "An Act to create a Drainage District, to be called the Sacramento River Drainage District, to establish a Board of Commissioners therefor, and to define their power and duties," approved April 1st, 1878, I herewith submit the following report of such work, with field-notes, maps and estimates of the cost of construction of the work proposed by the above bill.

Under Section 8 of this Act a party was organized, numbering thirteen, with Messrs. William Bassett, of Sacramento, and Horace D. Gates, of San Francisco, as Chief Assistants, and placed under my charge on the 1st day of June, 1878, for the purpose of making the surveys necessary to determine the practicability of the improvements contemplated in this Act, to wit: draining the surplus waters of the Sacramento River, and waters flowing from the east side of the Coast Range of Mountains, in the Counties of Yolo and Solano, into Suisun Bay, at a point removed from the present mouth of the Sacramento River, by making a cut through the Montezuma Hills.

The first camp was made at Denverton, Solano County, where, after a little time spent in disciplining the party, work was commenced, and a line run from a point on and near the head of Nurse Slough as the initial point, southerly across the tule lands to the end of the Potrero Hills, and thence skirting the edge of the hills to Montezuma Slough, which was found to be of large carrying capacity, being of an average width of 1,000 feet, and from 30 to 40 feet in depth, and of a comparatively direct course to the deep waters of Suisun Bay, near the head of the Straits of Carquinez.

The object of this line was to ascertain the practicability and the probable cost of taking a canal into this part of the bay. Offset and auxiliary lines were run in order to locate the numerous sloughs, with a view of selecting the most favorable route.

The line was mainly over wet tule land and narrow, deep sloughs, or so-called beaver cuts; the length with offset and auxiliary lines is $8\frac{2}{10}$ miles. The length of main line $4\frac{83}{100}$ miles, to the intersection with Montezuma Slough, and from this point to Suisun Bay, $6\frac{65}{100}$ miles. This line is denoted as "A" line in the note-books.

The line was next taken up at the initial point heretofore mentioned, and a base line run across the divide known as the Montezuma Hills, from the head of Nurse Slough to the head of the south fork of Lindsey Slough.

Contour lines were run both ways from the "base line" on the Nurse Slough side, and also on the Lindsey Slough, and offset lines were run each way from the summit, the object being to determine the lowest and shortest practicable route over this divide. Considerable time was devoted to this work, and an aggregate length of $63\frac{65}{100}$ miles of contour and offset lines were run, which resulted in the

location of the line shown on Plate No. 3, in connection with the contours, as the most practicable route for a canal. Subsequently a series of wells were bored on this line across the divide, 1,000 feet apart, to determine the material composing this portion of the Montezuma Hills. An accurate account was kept by one of the party detailed for this work, and samples taken of every change of stratum found in boring. The wells number thirty-one, aggregating in depth 536½ feet. The results of such borings are shown in detail on Plate No. 5, and in section on Plate No. 3, and the location of a portion where rock was found, on Plate No. 4.

The only rock found was on the westerly slope of the hills, and is a soft sandstone, offering little resistance to making the cut. The other portions of the hills were found to be composed principally of clayey soils, with some gravel and quicksand.

Of the contour lines run, the first, or one of the least elevation, on the west side of the divide, is 10 feet above low tide datum line at Denverton, the one on the east, or Lindsey Slough side, being 15 feet above low tide or datum line at Denverton, each successive one at 5 feet greater elevation, up to 30 feet, the next one being 37 feet above low tide, the next one 40 feet, and so on up to 90 feet, the greatest elevation on the line adopted for the route of the canal being 37 feet above datum, or about 30 feet above ordinary high tide at Denverton. This located line is denoted as B line in the note books. It is perhaps well to remark that on this as well as much of the subsequent work, the party was greatly annoyed and the work greatly impeded by the gnats, which on still days swarmed in countless myriads from the cracks in the adobe, attacking all the exposed parts with their venomous bite, the effects of which often remained for weeks.

In connection with this line across the divide, an auxiliary line was run along the northern base of the Potrero Hills, connecting with Suisun Bay by the way of Suisun Slough. This line is denoted as Z line in the note-books, and is, with the continuation of the line into Fairfield, 9 miles in length. A line was also run over the first pass to the east of Denverton, but on attaining an elevation of 97 feet above low tide it was abandoned. The length of this line was $2\frac{41}{100}$ miles, and is denoted as C line in the note books.

The located line across the divide was then taken up, and extended northerly toward Gray's Bend, following as nearly as practicable the natural grade line of the country, rising at the rate of 6 inches to the mile. Offset lines were run each way from this line at different points, in order to determine the slope of the ground from west to east. At the sink of Putah Creek back-water from the tule was met with, and a detour made to avoid it; an offset line was run around the overflowed district, the line being again taken up on the opposite side, at a point at or near Swingle's Station, on the California Pacific Railroad, and continued. Back-water was again met with on reaching the tule directly south of Gray's Bend and east of the sink of Cache Creek, and a second detour made, crossing Cache Creek above the sink and running into Knight's Landing, thence down the Sacramento River to Gray's Bend.

From Gray's Bend a line was run back towards the point on the other side of the tule, where the back-water was met, a distance of $\frac{89}{100}$ miles, as far as the water permitted.

High water at Knight's Landing was found to be $41\frac{5}{10}$ feet above low tide at Denverton, and at Gray's Bend 39 feet above low tide.

The total length of this line, including offset lines, is $77\frac{33}{100}$ miles. The length of main line, not including offset or auxiliary lines, is $44\frac{36}{100}$ miles. The object of this line being to determine the amount of fall from high water in the Sacramento River, at Gray's Bend and Knight's Landing, to low tide at Suisun Bay, and also to determine the most practicable route for a canal, diverting a portion of the waters of the Sacramento River at or near Gray's Bend, and intercepting the waters of Cache and Putah Creeks and other waters coming in from the west before they have entered the tule basin, and keeping on the high land, reach the Montezuma Hills at a point with as great an elevation as can be attained, after allowing grade enough to give velocity to the waters of the canal.

A meander line, having its initial point at Gray's Bend, was next run down the west bank of the Sacramento River, with offset lines running into the tule on the west, and frequent cross sections of the river banks, with measurements of the width of the river, to Rio Vista; connection was made with Sacramento City and with a series of gauges put up by the State Engineer Department. This work was done in connection with that of the State Engineer Department. Permanent benches and points were established at intervals of 1 mile as a base for future operations. Mr. D. D. Griffiths, of the State Engineer Department, accompanied this survey as topographer. The survey was greatly impeded by the difficulty of working through the dense thickets of brush bordering the banks of the river, and by continued sickness in the party, caused by the intense heat and the malaria; also from the effects of the poison oak which here abounds.

The total length of this line, including offsets and cross sections, is $98\frac{98}{100}$ miles, the length of the offset and cross section lines being $32\frac{47}{100}$ miles. This line is denoted as No. 10 in the note-books.

The object of this survey was to gather data to determine the effect upon the river by diverting a portion of its waters by means of a canal into Suisun Bay, and to determine the amount necessary to be so diverted in order to produce a certain diminution of the volume of the waters of the river at all points below the point of diversion, and to obtain a correct alignment of the Sacramento River.

From a point near Rio Vista a tie line was run across to and connected with the "B" line. The length of this line was $9\frac{41}{100}$ miles.

A survey of Putah Creek was then made, a line being run from the sink of the north branch or old channel of the creek, up the creek to a point on the Rancho Rio de las Putos, near Green McMahon's residence, said point being above the line of overflow from the creek, where a section of the creek was prepared for gauging during the next high water in the creek. A line was then run down the south branch or new channel of Putah Creek to the tule, with numerous offset and cross section lines. The total lengths of these lines are $31\frac{71}{100}$ miles, and are denoted in the note-books as Putah Creek surveys, and shown on Plate No. 6.

The object of this survey was to determine the maximum volume of water entering the tule basin from this source during the flood season, the most practicable route for taking it into a main canal, and an estimate of the amount of debris brought down and deposited in the tule.

A survey with the same object in view was made of Cache Creek. Total length of line, including cross sections, $9\frac{1}{100}$ miles, is denoted in note-books as Cache Creek surveys, and shown on Plate No. 7.

A series of lines were run into and across the tule from different points on the "B" line, viz.: one into the Big Lake Basin $4\frac{53}{100}$ miles in length; one across the tule at its narrowest point, where the old Williams' grade crossed at the head of Babel's Slough, $7\frac{7}{100}$ miles in length, and one running down Cache Slough $3\frac{6}{100}$ miles in length. These lines are shown on Plate No. 1, and profiles of same are shown on Plate No. 2.

This finished the work in the field, and the party was disbanded November 5th, 1878. On the 1st of October, Horace D. Gates severed his connection with the party to accept a position on the Government survey, the vacancy being filled by Norman B. Kellogg, of San Francisco.

Subsequently a line of levels was run from Rio Vista to Denverton, thence to Lindsey Slough, and thence to Cache Slough, putting up and connecting gauges at these points.

Upon finishing the work in the field, an office was established at 53 J Street, Sacramento, and the work of making maps of the surveys, with plans for the work proposed, and estimates of the cost of same, was commenced, William Bassett, of Sacramento, being Chief Assistant.

A general map of the district was made on a scale of 14,000 feet to 1 inch, and a map of the profiles of the surveys, Plate No. 2, for publication. The general map or maps of the Sacramento River Drainage District surveys shows the boundaries of the district, the sections within the district only being numbered; the Montezuma Hills, the Sacramento River, the tule basin, the line of a *proposed* main canal from Knight's Landing to Suisun Bay, the proposed subsidiary canals, the line of lowest levels through the tule from Gray's Bend to the Montezuma Hills, in connection with a drainage cut through those hills, the lines D, E, F, and B L, run into and across the tule basin, with the main points of interest.

Plate No. 2.—Profiles of surveys of Sacramento River Drainage District, shows a profile of the line of a proposed main canal, a profile of lowest line of levels through the tule, a profile of the bank and bed of Cache Creek, a profile of the bank and bed of Putah Creek, a profile of the bank and bed of the new channel of Putah Creek, a cross section of the tule basin at line "D" on the general map. (The notes of this cross section were obtained from the State Engineer Department.)

A cross section of the tule basin at line "E" on the general map, the notes of which were obtained from the Engineer Department of the Central Pacific Railroad; a profile of the line "B L" shown on the general map, and a cross section of the narrowest part of the tule basin at line "F," also on the general map.

Plate No. 3.—A map of the contours of Montezuma Hills, scale 1,000 feet to 1 inch, showing the contours run to determine the lowest pass over this divide. The located "B" line as being the most practicable route for a canal.

The line across the tules from the head of Nurse Slough to Montezuma Slough, the location of Denverton, the high land of the Potrero Hills, Lindsey, Nurse, and Montezuma Sloughs, a profile of the "B" line showing the shape of the divide, and a section showing the strata in connection with a profile of a drainage cut through the hills.

Plate No. 4.—Showing the location of the sandstone ridge on the

westerly slope of the divide near Denverton and the wells bored to ascertain the extent and depth below the surface of said ridge.

Plate No. 5.—A profile of "B" line across the divide, showing the wells bored and the results of such borings in detail, and the grade lines of the proposed main canal and of a drainage cut respectively.

Plate No. 6.—Map of Putah Creek surveys, scale 1,000 feet to an inch, showing the surveys in detail. Two cross sections, one of the old and one of the new channels, showing their relative carrying capacities. Two cross sections taken above the line of overflow to assist in determining the volume of flow. A profile of the bank and bed of the creek from a point above the line of overflow down the old channel to the tule, and of the new channel from its head to the tule, and showing the Putah Creek subsidiary canal, and its junction with the proposed main canal.

Plate No. 7.—Map of the Cache Creek surveys, scale 1,000 feet to the inch, showing the surveys in detail, with two cross sections taken at points above the line of overflow to assist in determining the volume of flow. A profile of the bank and bed of the creek from a point above the line of overflow to the tule, the Cache Creek subsidiary canal and its junction with the proposed main canal, and the location of Gray's Bend on the Sacramento River, in its relation to the sink of Cache Creek.

Under the direction of Chief Engineer Isaac W. Smith, a proposed line for a main canal was adopted, having its initial point at Knight's Landing, 8 feet below the high water of 1878, and running thence, following as nearly as practicable the natural surface slope of the ground, with a grade falling at the rate of 4 inches to the mile, to the Montezuma Hills, reaching them at a point with an elevation of $19\frac{7}{100}$ feet above low tide, thence through the hills with an increased grade of 6 inches to the mile $3\frac{19}{100}$ miles to the ledge of rock aforementioned, an overfall being made at this point of 10 feet, and thence continuing said grade to a point in the tule south and west of Denverton, when the grade runs out on the surface of the tule; thence with a grade conforming with and to the surface of the tule to Montezuma Slough.

This line for a proposed main canal is shown on the general map of the district, and a profile of same on Plate No. 2.

Estimates were made of the amount of earth-work necessary to construct this canal, based on the following cut and levees:

Beginning at the Sacramento River, at the Town of Knight's Landing, with a cut —— feet wide on the bottom, with side slopes of 1 to 1, and following along the line shown on the general map with a grade 8 feet below high water of 1878 at point of beginning, and falling at the rate of 4 inches to the mile, $\frac{85}{100}$ miles, to where the grade of the bottom of the cut runs on the natural surface of the ground. Levees are built on each side of this cut, beginning at Knight's Landing and running thence parallel, with a width on top of 5 feet, with an inside slope of 3 to 1, and an outside slope of 2 to 1, with a grade on top conforming with and 9 feet above the grade of the bottom of the canal, along said line shown on general map, $7\frac{30}{100}$ miles to the junction with the Cache Creek subsidiary canal, as shown on general map, also on Plate No. 7. At the point of junction the main canal is widened, by placing the levees a greater distance apart, to a width of —— feet, and continued thence, with the same relative grade, $14\frac{54}{100}$ miles, to the junction with Putah Creek

subsidiary canal, as shown on the general map, and also on Plate No. 6. At the point of junction the width of the canal is again increased in proportion to the amount of increase in the volume of water to be carried.

Continuing thence, with the same relative grades, $20\frac{49}{100}$ miles, to where the grade of the top of the levee runs out on the natural surface of the ground at the Montezuma Hills. The canal is continued through the hills by means of a cut 600 feet wide on the bottom, with side slopes of 1 to 1, beginning back $\frac{46}{100}$ of a mile from the end of the levees and running thence, with an increased grade of 6 inches to the mile, $3\frac{19}{100}$ miles, to where the overfall is made.

Continuing thence $1\frac{42}{100}$ miles to where the grade runs out on the surface of the tule, the canal is carried across this tule land by means of two parallel levees, beginning back $1\frac{14}{100}$ miles from the end of the cutting, and running thence with a grade conforming with the surface of the tule $5\frac{56}{100}$ miles to a junction with Montezuma Slough. The total length of this proposed main canal, from Knight's Landing to Montezuma Slough, is $50\frac{41}{100}$ miles.

The Cache Creek subsidiary canal, for the purpose of diverting the waters of Cache Creek into the main canal, begins at a point where the Northern Railway crosses the creek, near the Town of Yolo, said point being above the line of overflow of the creek, and running thence down the present channel, utilized by means of levees on either side, with a width of 5 feet on top, with an inside slope of 3 to 1, and an outside slope of 2 to 1, and with a grade conforming to the fall of the bed of the creek $4\frac{55}{100}$ miles, to where the waters are diverted into a cut 150 feet wide on the bottom, with side slopes of 2 to 1, with levee of similar dimension to the foregoing on each side; running thence, with a curvature of 5,730 feet radius $2\frac{58}{100}$ miles, to a junction with the main canal, shown on general map and also on Plate No. 7.

The Putah Creek subsidiary canal, for the purpose of diverting the waters of Putah Creek into the main canal, begins at a point on the creek above the line of overflow of the waters of the creek, said point being located on the creek 2,900 feet above the residence of Green McMahon, and running thence down the present channel, utilized by means of levees on either side of said channel, with a width on top of 5 feet, with an inside slope of 3 to 1, and an outside slope of 2 to 1, $5\frac{31}{100}$ miles to the forks of the new and old channels, thence down the new channel, and by line shown on the general map, and also on Plate 6, $7\frac{7}{100}$ miles to a junction with the main canal. The total length of this subsidiary canal is $12\frac{38}{100}$ miles. These estimates are hereunto appended.

An estimate was also made of a drainage cut through the Montezuma Hills, from Lindsey Slough to the tule a little south and west of Denverton, the bottom of this cut to be 200 feet in width, with slopes of 1 to 1, having a uniform elevation of $6\frac{5}{10}$ feet above low tide; the average elevation of high tide is also hereunto appended. The length of this cut would be $7\frac{9}{10}$ miles. A profile of the cut is shown on Plate No. 2, in connection with that along the line of lowest levels through the tule; also on Plate No. 3, in connection with a section showing strata of Montezuma Hills, the alignment being shown on general map.

On Plates Nos. 6 and 7 is shown the highest water mark of 4th and 5th of March, 1879, with the cross sectional area of Cache and Putah

Creeks, respectively. Observation of the velocity of the current of Putah Creek was made in company with Mr. Bassett on the 5th of March, which resulted in a mean surface velocity of $12\frac{8}{10}$ feet per second, with a depth of $24\frac{7}{10}$, the water falling at the rate of 1 foot per hour.

The hight of the highest water was noted, being $5\frac{1}{10}$ feet in excess of the observed hight, which would give a maximum depth of $30\frac{5}{10}$ feet. A comparison was made between the observed velocity in feet per second, and that obtained by formula—

$$\frac{l\sqrt{\frac{A}{F\times lp}}}{}2gh=V$$

A being the main area of cross section, l= length of observed section p= perimeter, h= fall in bed of creek, F=co-efficient of friction, g= velocity acquired by falling bodies at the end of the first second, V= mean velocity in feet per second, the result being by observation $12\frac{8}{10}$ feet per second for a mean surface velocity, and $12\frac{8}{10}$ feet x $\frac{85}{100}$ gives $10\frac{9}{10}$ feet, this for a mean velocity of the whole cross section per second. By formula a mean velocity of the whole cross section of $12\frac{3}{10}$ feet was obtained, which, under reversed circumstances, that is to say, with the creek rising instead of falling, I assume to be approximately correct.

Then using this formula with a depth of water of $30\frac{5}{10}$ feet, a cross sectional area (A) of 5,751 feet, length of section (l) 1,000 feet, a perimeter or water profile (p) of 274 feet, a fall (h) of 1 foot, g= 32.166 feet, and F= .00743, V= 13.48, the mean velocity in feet per second of the entire area of the creek, and the area 5,751x$13\frac{48}{100}$ mean velocity, gives 77,523 cubic feet per second as the maximum volume of flow.

An observation of Cache Creek other than noting the hight of highest water, was not made, the similarity of the two creeks making an observation of both not essential for the purpose of this report, as only an approximation is aimed at. High water of March 5th, 1879, gives a mean depth of 23¼ feet in the section taken of the creek, which gives a mean area of 3,558 feet, a perimeter of 235 feet, fall of 1 foot, length 1,000 feet, and by preceding formula a mean velocity of $11\frac{41}{100}$ feet per second is obtained, and 11.41x$35\frac{58}{100}$ gives 40,596 cubic feet per second as the maximum volume of flow.

There is appended hereunto tables showing the total mileage of the surveys, the total number of acres in the district, as computed from surveys on file in the Surveyor-General's office, and the relative hights of the main points in the district.

Respectfully submitted,

JIM. C. PIERSON,
Engineer in Charge.

TABLE

Showing the total length in miles of the various lines constituting the Sacramento River Drainage District surveys.

Main line	132.14 miles.
Offset and tie	107.00 miles.
Cross section	11.57 miles.
Contour	57.22 miles.
Putah Creek	31.62 miles.
Cache Creek	9.00 miles.
Total	348.55 miles.

TABLE

Showing the number of acres in the Sacramento River Drainage District.

Sacramento County	166,121.80 acres.
Solano County	49,281.36 acres.
Yolo County	147,065.32 acres.
Total	362,468.48 acres.

TABLE

Showing the relative elevation of principal points in the Sacramento River Drainage District.

Low tide at New York Landing (Hall's base)	1.26 feet.
Low tide at Denverton	0.00 feet.
High tide at Denverton (average)	6.50 feet.
High tide at Denverton (extreme)	10.00 feet.
Surface of tule from Denverton to Montezuma Slough (average)	6.50 feet.
Surface of tule at Lindsey Slough	6.50 feet.
Surface of tule at Big Lake	3.00 feet.
Surface of tule at its narrowest point (opposite Babel Slough)	9.00 feet.
Surface of tule at the sink of the new channel of Putah Creek	12.30 feet.
Surface of tule at the sink of the old channel of Putah Creek	26.00 feet.
Surface of tule opposite Sacramento	11.50 feet.
Surface of tule opposite Colonel Hall's	20.00 feet.
Surface of tule opposite Gray's Bend	26.66 feet.
Surface of tule at sink of Cache Creek	27.50 feet.
Summit of pass over the Montezuma Hills	37.08 feet.
Surface of ground at Maine Prairie	8.00 feet.
Surface of ground at Knight's Landing	37.10 feet.
Surface of ground at Gray's Bend	34.60 feet.
City base, Sacramento	4.96 feet.
Flood-hight of water at Maine Prairie, 1861 and 1862, 18.02; of 1878	16.70 feet.
Flood-hight of Sacramento River at Newtown Landing, of 1878	16.24 feet.
Flood-hight of Sacramento River at Richland	20.45 feet.
Flood-hight of Sacramento River at Babel Slough	24.36 feet.
Flood-hight of Sacramento River at the chicory ranch	27.97 feet.
Flood-hight of Sacramento River at Sacramento	30.92 feet.
Flood-hight of Sacramento River 10¾ miles below Freeport	32.05 feet.
Flood-hight of Sacramento River 2½ miles below Fremont	33.58 feet.
Flood-hight of Sacramento River at Gray's Bend	37.00 feet.
Flood-hight of Sacramento River at Knight's Landing	41.50 feet.
Flood-hight of Cache Creek at Yolo	88.00 feet.
Flood-hight of Putah Creek at Green McMahon's	100.76 feet.